

80, a training module 90, a cyclic prefix module 100, a Fast Fourier Transform module 110, a frequency domain equalizer 120, a decoder 130 and a bit loading module 140. As will be appreciated by one of ordinary skill in the art, various other components may be present in a DSL modem, however have been omitted for the sake of clarity.

**[0022]** While the exemplary embodiment illustrated in the Fig. 1 shows the modem 5 and various components collocated, it is to be appreciated that the various components of the modem can be combined or located at distant portions of a distributed network, such as a local area network, a wide area network, an intranet and/or the Internet, or within a modem. Thus, it should be appreciated, that the components of the modem 10 can be combined into one device or collocated on a particular node of a distributed network or combined into one or more of a CO or CPE modem. Thus, it will be appreciated from the following description, and for reasons of computational efficiency, that the components of the modem 10 can be arranged any location, such as in a general purpose computer or within a distributed network or dedicated modem without affecting the operation of the system. Furthermore, the term module as used herein is to be understood to include, but is not limited to, one or more of hardware components and/or associated software for performing a given function.

**[0023]** In operation, the encoder, in cooperation with the bit loading module 10, receives the input data bit stream and encodes it into M QAM constellation points. This encoding is accomplished in accordance with a bit loading table that is stored in the bit loading module 10. The bit loading table defines the number of bits carried by each tone.

**[0024]** The IFFT module 30 receives the encoded data and determines a sum of N carriers each modulated by a predetermined phase and amplitude. Specifically, the input to the IFFT module 30 is a vector of QAM constellation points – N complex numbers, defining the amplitude and phase of each carrier.

**[0025]** The cyclic prefix module 40 receives the output of the IFFT module 30 and separates the received symbols in time in order to decrease the intersymbol interference (ISI). As is well known, the signal passing through the line is linearly convolved with the

impulse response of the line. If the impulse response is shorter than the duration of the cyclic prefix as discussed above, each symbol can be processed separately, thereby eliminating the intersymbol interference.

[0026] The echo canceller 50 generates a replica of the transmitted signal that leaks back into the receiver. Upon subtraction of the near-end echo-replica, the received far-end signal can be processed as if its only impairment has been the channel induced noise sources. In general, the echo cancellation in DSL systems considers the asymmetric upstream/downstream nature that results in different sampling rates for upstream and downstream communications. However, many variations and methods for reducing echo are well known to one of ordinary skill in the communications arts and will not be discussed herein.

[0027] The time domain equalizer module 80 is a filter designed to minimize the intersymbol interference and interchannel interference (ICI). This is done by reducing the total impulse response of the line to the length of the cyclic prefix, as discussed above, such that one symbol does not interfere with the next symbol and accordingly intersymbol interference can be reduced or eliminated.

[0028] The cyclic prefix module 100 complements the cyclic prefix module 40 and forwards its output to the FFT module 110. The FFT module 110 complements the operation of the IFFT module 30 by transforming the received N carriers back into amplitude and phase information, which is then decoded back into bits in cooperation with the decoder 130 and the bit loading module 140.

[0029] The training module 90 manages a number of training features that are present in the ADSL modem system 5. However, for the sake of clarity, only the training related to the application of this invention will be described. Clearly, one of ordinary skill in the art will appreciate that additional training will be present during the training and/or operating condition of a typical DSL modem.

[0030] In particular, during a portion of initial training, the DSL modem 5 enters into reverb. During this reverb training, and in conjunction with the training module 90, an

estimate of the channel frequency response ( $H_k$ ) is determined. For example, as discussed in the Sandberg article referenced above, the channel frequency response can be estimated.

**[0031]** Next, a reverb based TDQ training algorithm, such as the one discussed the Sandberg article referenced above, is used to determine the initial TDQ coefficients. Upon determination of these coefficients, which are stored in a memory (not shown) in the training module 90, medley is commenced. During medley, the training module 90, operating on data received from the echo canceller 50, performs one or more supplemental TDQ training sessions according to the systems and methods of this invention. Then, the updated time domain equalizer coefficients are provided from the training module 90 to the time domain equalizer 80.

**[0032]** Based on the determined TDQ, additional medley training is performed such as, but not limited to, FDQ training and SNR measurements for bit loading. At this point, the DSL modem 5 is ready to enter showtime.

**[0033]** Fig. 2 outlines an exemplary method of performing supplemental training to determine updated time domain equalizer coefficients according to an exemplary embodiment of this invention. In particular, control begins in step S100 and continues to step S110. In step S110, reverb is commenced. Next, in step S120, the channel frequency response ( $H_k$ ) is estimated. Then, in step S130, a reverb based TDQ training algorithm is used to determine the initial TDQ coefficients. Control then continues to step S140.

**[0034]** In step S140, medley is commenced. Next, in step S150, the supplemental TDQ training in accordance with this invention determines the improved time domain equalizer coefficients by maximizing the number of bits per frame. Then, in step S160, the updated time domain equalizer coefficients are provided to the time domain equalizer for use during showtime. Control then continues to step S170.

**[0035]** In step S170, based on the determined TDQ, additional medley training such as frequency domain equalizer training and signal-to-noise ratio measurements for the determined time domain equalizer coefficients that are used for the bit loading is completed.